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OPTICAL THICKNESS AS RELATED TO POLLUTANT EPISODES AND THE CONCENTRATION OF VISIBILITY DEGRADING POLLUTANTS

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16. Abstract

A network of six sun photometers was placed in the central and northeast United States during the months of July through October, 1981. The objective of the program was to obtain measurements of atmospheric turbidity which can be related to the concentration of visibility-degrading pollutants in the atmosphere. These measurements will serve as ground truth for a program (R. Fraser, NASA/Goddard) to develop remote sensing techniques for measuring the vertically integrated aerosol concentrations in pollution episodes.

The sun photometers measure the direct solar radiation in four passbands: 380 nm, 500 nm, 875 nm and 940 nm. The first three passbands will be used for measuring the aerosol optical depth and the last for measuring precipitable water.

Stations were established in: St. Louis, Missouri; Columbus, Ohio; State College, Pennsylvania; Philadelphia, Pennsylvania; Narragansett, Rhode Island; Greenbelt, Maryland.

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Introduction

A sun photometer network was established in the northeast United States during the late summer and early fall of 1981. The photometers were used to make measurements of aerosol optical depth at selected time intervals. These measurements serve as a data base for the development of an algorithm for the measurement of aerosol optical depth from satellite systems.

The sun photometer instrument used is a four-channel device which incorporates interference filters centered at 380 nm, 500 nm, 875 nm and 940 nm. The 940 nm passband is used for estimating precipitable water. The other three are selected for aerosol measurements. The instrument is a hand-held device with a digital readout display and a peak-hold circuit to facilitate measurements. A detailed description of the instrument and the observing techniques employed is found in Appendix I (Sun Photometer Measurements - Instructions to Observers).

The photometers were distributed so as to obtain good coverage in the northeast portion of the United States, an area which is often affected by dense pollutant hazes. The selected sites are: St. Louis, Missouri; Columbus, Ohio; State College, Pennsylvania; Philadelphia, Pennsylvania; Narragansett, Rhode Island; Greenbelt, Maryland. A list of station locations and observers is found in Appendix II.

The data gathering protocol calls for a sequence of a minimum of four to a maximum of seven readings; these were to be made in the morning at specified time intervals. The time intervals were be selected so as to provide a good range of sun angles during the morning from about 0700 AM LST until about 1200 LST (see Appendix I).

Observers were paid for the observations that they made according to a fixed schedule (see Appendix III, Cover Letter to Observers). As an inducement to the observers, prizes were offered to the persons who recorded the greatest amount of data.

All instruments were thoroughly inspected and intercompared prior to going into the field. At the completion of the experiment, the instruments were recalibrated in Miami.

Data was recorded on a standard form (see Appedix IV). Data was returned to Miami at the end of each week by means of pre-addressed, post-paid envelopes.

Sun Photometer Calibrations

The instruments were calibrated on three occasions: 1) November and December, 1980; 2) June and July, 1981, and 3) April, 1982.

1. The calibrations in November and December, 1980, were carried out at the completion of a previous major field program. For this purpose a Langley

calibration was carried out in Miami on instrument UM 322 which was then used as the reference standard. All other instruments were calibrated against UM 322 using neutral density filters.

2. The calibrations of June and July, 1981, were merely a recheck against UM 322 to verify performance prior to sending the instruments out into the field for the contract experiment.

3. The calibrations of April, 1982, were an intensive cross check between UM 322 and UM 323 against all other photometers

The University of Miami sunphotometer UM 323 had been sent to NOAA/GMCC, Boulder, Colorado to be used in an extensive intercomparison study of sunphotometers from a wide range of sources and institutions. The intercomparisons were carried out under the supervision of E. Dutton and J.J. de Luisi from 19 October through 4 November 1981. During that period, extensive data were obtained at frequent time intervals at relative air masses (M) ranging up to 20 on six days. On half of those days, however, readings were possible only during the morning or the afternoon as a consequence of the presence of clouds during the balance of the day.

For each of the half-days, the raw data for the blue, green, and red channels were plotted as a Langley plot (i.e.,

the natural log of the instrument response versus the relative air mass, (M)). For the water channel, lnQ (where Q is the response in the water channel divided by that of the red channel) was plotted versus the square root of M. Each of the plots was visually examined for obvious outliers and/or nonlinearity; the outliers and the data obtained during periods of obviously changing turbidity were deleted from the final data sets. Regression analyses were performed on each of the final data sets to determine the apparent I_o's and Q_o for the instrument.

For each day of the three days in which both morning and afternoon data were obtained, it was apparent that the turbidity was either increasing or decreasing slightly throughout the day. With a constantly increasing turbidity, the apparent I_o's from the morning data will underestimate the true Io while those from the afternoon data will overestimate it; the opposite is true in the case of decreasing turbidity. The best estimate of the true I_o is obtained from the mean of the highest underestimate and the lowest overestimate, which are generally within a percent or two of one another.

The best estimate of the I_o's and Q_o for photometer UM323 from the Boulder data (1981) are given below along with the estimates obtained from the calibration against UM 322 in 1980.

Channel		1981	1980
Blue	$I_o(380)$	39.1 (+2%)	39.2
Green	$I_o(500)$	184.3 ($\pm$.5%)	182.5
Red	$I_o(875)$	125.8 ($\mp$.4%)	125.7
Water	$Q_o(945)$	2.03($\pm$ 3%)	2.06

The 1981 results are in excellent agreement with those of 1980, indicating that no significant alteration in instrument response had occurred during the one year period.

In Table 1 we summarize the calibration constants for all instruments as determined in each of the three calibration runs. For the most part, the instruments performed reasonably well. The maximum range of values for the three calibrations for any one instrument was generally less than 2% for the red and green channels. The blue channel was considerably worse with an average change of 6%.

The apparent change in calibration constants is attributable to a number of factors. First of all, we are comparing, in effect, calibrations derived from two independent "prime" calibrations, that of UM 322 in Miami in Period 1 and that of UM 323 at Boulder. Shaw, in his article on sun photometry (Bull. Amer. Meteorol. Soc. 64, 4-10, 1983), points out the severe problems of doing Langley plots in continental environments. He states that one can easily get "excellent" Langley plots that are in reality not excellent. That is, the aerosol content builds up or falls off in a systematic manner so that one gets a deceptively "good" straight line in the Langley plot. For example, Shaw

finds that Langley calibrations performed by him at Tucson show consistently lower Io values by 1 to 3% than calibrations performed at Mauna Loa. Consequently, he recommends that the only good way to do calibrations is at a site such as Mauna Loa; these measurements should be made concurrently with aerosol measurements to ensure that the aerosol concentration does not change. Unfortunately, we could not do our calibration at Mauna Loa.

Another problem has to do with the fact that we had to send instrument UM 323 to Boulder for the intercomparison; we could not part with our "prime" reference, UM 322, for an extended time. Thus, we had to transfer the UM 323 calibration through UM 322 to the other instruments. This problem was exacerbated by the fact that the Boulder intercomparison lasted much longer than anticipated. Thus we could not carry out our final calibration transfer until some six months after the field experiment had been completed.

The relatively poor response of the blue channel is disturbing but not completely unexpected. The transmssion through the filter is so low that we must use the maximum gain of the integrated photo-detector/amplifier. Also, as Shaw also notes, the photometers are subject to much greater drifts, about 1% per year, in the blue wavelengths than in the longer wavelengths. Also, we have experienced problems with deterioration of the blue filters.

Despite the fact that the blue channel performance is being pushed to the limit, a perusal of the data indicates that it did perform satisfactorily. For example, on a number of days data was obtained at Goddard Space Flight Center using sun photometer No. 320 at frequent intervals beginning very early in the morning. On many of these days, the blue channel was yielding initial readings of 0.0 and .1 (i.e., the minimum resolvable reading); over the following hour or two these readings would increase dramatically as the solar elevation increased. Despite the extremely low initial readings the computed turbidities in the blue channel and the resulting alpha values were often remarkably constant over that time interval. An example is August 5 when readings began at 7:12 AM. The initial readings in the blue channel were 0.1 and 0.0. Readings were subsequently taken every few minutes and the readings in the blue channel increased to values of about 5. Over the course of the approximately 4 hour set of readings, the computed turbidities in the blue channel were remarkably consistent as were those in the green and red channels. This set of readings attest to the stability and linearity of the blue channel even in the extreme low end of its range. Another data set from Goddard on August 28 yields a similar validation of performance in the blue channel.

The final selection of calibration constants are presented in Table 2. These values are the means of the calibration constants obtained in calibration periods 2 and 3; that is, the ones before and after the field program.

Data Processing

The data received from the field stations was transferred to punched cards. These values were converted to aerosol optical depth. The computation incorporates a correction for the temperature coefficient of the sun photometer detector. All data print outs have been checked for obvious errors and they have been corrected accordingly. Copies of all data have been delivered to Dr. Bob Fraser in both punched card form and as computer print-out that presents all input data as well as the computed values of aerosol optical depth and alpha (the Angstrom wavelength exponent). A copy of a letter from Dr. Fraser acknowledging receipt of these materials is presented in Appendix V.

Discussion

In this section, we will make some general observations about the character of the data obtained during the experiment. We will point out some of the interesting features in the data, features that could reflect on either the character of the aerosol or on instrument performance.

In perusing the data, we looked for: days that appeared to have relatively constant turbidity; days when the turbidity changed dramatically in a systematic manner; sequences of days showing large changes in parameters.

The calculated values of alpha can be very sensitive to relative changes in the measured aerosol optical depth or to errors in these measurements. Thus, a perusal of the alpha values is often helpful in identifying trends or problems with data points (or entire data sets). Assume for purposes of illustration that we have error confined to one passband in a pair of measurements in two different passbands - for example, in the red channel of a series of measurements in the red and green. Then the error in alpha will be:

$$\Delta\alpha \quad = \quad \Delta \ln \tau_R \; / \; 0.5653$$

The fractional error in the calculated alpha will be:

$$\frac{\Delta\alpha}{\alpha}$$

Thus small errors in the measured τ_R will have an increased impact at low aerosol optical depths and at low values of alpha. This is illustrated in Table 3 which shows the computed values of alpha (green-red) for induced errors of ± 0.01 in the value of τ_R. Error alphas are computed for various values of hypothetical "true" alpha and for various values of τ_R. For example, an error of ± 0.01 for $\tau_R = 0.025$ will yield a range of alpha values of -0.5 to 1.0 for a nominal "true" alpha of 0.1. An assumed error of 0.01 is

realistic. Of course, the problem would be compounded if there were opposing errors of 0.01 in both channels. This could explain some of the trends in alpha observed at some stations, especially on days with low aerosol optical depths.

In the following sections we comment on each of the data sets. In Table 4 we list the number of observations made each day at each of the observing sites.

Goddard

We have previously commented on the excellent quality of the Goddard data and the great abundance of data points. Because of the large number of data points, we are able to discern more clearly any trends in the aerosol optical depth values and also we are better able to reject anomalous data points. On a number of days, the aerosol optical depths were relatively constant and relatively low : 7/11, 7/23, 7/30, 8/17, 8/18, 8/20, 8/23 and 9/9. On many of these days the alpha values were relatively stable during the entire day and they were relatively uniform across the spectrum.

However, on some days there were interesting variations in the alpha values. In some cases the alphas changed as the day progressed and in other cases the value of alpha changed across the spectrum. Interesting examples occurred on 8/17, 8/18, 8/20, 8/23 and 8/28. In most cases where alphas changed across the spectrum, the alpha values were relatively

high in the blue/green channel, in the range of 1.5 to 2.5, generally; in contrast, in the green/red, values were below 1 and often ranged down to .5 and sometimes below. These changes appear to be real and significant. Compare for example, 7/30 with 8/23. In both cases the turbidities in the red channel were approximately the same; the turbidities in the green and the blue were progressively and significantly different.

An interesting case worthy of further investigation is that of 8/23. On this day, alphas were very low in the blue/green channel, on the order of 1 or less; in contrast, the alphas in the blue/red and the green/red were 1.5 or higher. Despite the fact that some of the especially low alphas in the blue/green occurred during low sun angles, there seems to be a real change occurring in the properties of the aerosols during this day.

In conclusion, we can state that this data set is a very impressive one indeed.

Philadelphia

This data set shows some trends which could be attributable to real changes in aerosol character. On a number of days the turbidity in the red channel was on the order of .05 to .1; as the day progressed, the green/red alpha values gradually dropped from about 1.5 to down to 0.5

or so. Examples are on 7/23, 8/18, 8/21, 9/23, 9/24, 9/25, 9/28, 9/29 and 10/27. The turbidity changes appear to take place in the green channel. For example, on 9/24 the turbidity in the red channel increases slightly during the course of the morning from .061 to .072. In contrast, the turbidity in the green channel drops from .143 and .185 to .086. On 9/29 the turbidity in the red channel was .04 early in the morning and was essentially the same value at 10:25; however, in the green channel the turbidity drops from .092 to .037. The same sort of trend appears to be occurring to some degree in the blue channel.

It is interesting to compare the Philadelphia data with that of Goddard. Because they are located in the same general region, we should expect some similarities. However, the Philadelphia unit is located in the center of an urban area whereas Goddard is relatively rural. The first day when there is data at both stations is July 18. On that day there were two observations at Philadelphia and fourteen at Goddard. At Goddard, the greens were about .5 and the reds about .15/.16 in the mid morning. At Philadelphia, the greens were .3/.4 and the red .13/.16. The green/red alpha at Goddard was about 2.0 while at Philadelphia it was about 1.5/1.6. There was also data at these stations for the succeeding 3 days. On the 19th at Goddard, the greens were very consistent at about .63 to .60, reds were very

consistent at .20, and blues were about .95/.98. At Philadelphia on July 19, turbidity values were a bit lower than at Goddard; however, alpha values were similar.

Note that on 8/17 we have the first day at Goddard when we see a significant decrease in alpha in the green/red. A corresponding change occurred in Philadelphia on this day. Similarly on 8/18 the alphas in the green/red decreased markedly at Philadelpia and also at Goddard. This was another day when turbidities were quite low at both locations.

However, in general, low green-red alphas occurred considerably more frequently at Philadelphia than at Goddard. Because low alphas are caused by relatively higher concentrations of large particles, we could attribute these changes to an increase in traffic-generated large particles as the day progresses.

Rhode Island

This data set is not as extensive as some of the others. There were problems with increasing amounts of cloud as the experiment progressed. Also, because of the proximity to the coast, fog was a problem. The instrument at Rhode Island, No. 317, seems to have performed satisfactorily. Alpha values appeared to be relatively uniform across the spectrum on many days. However, on a number of occasions, the alpha

values in the blue/green channel were often relatively high, approximately 3 or greater. Some of these occasions were on days when the turbidities were low. An example is on 7/30 and 7/31. Another example is the extensive series of measurements made on 8/17, 8/18, 8/20 and 8/21. The turbidity in the red channel on these occasions was on the order of .03 and .04 whereas those in the green were in the general range of .5 to .6 or .7.

An extended period of low turbidities occurred at Rhode Island and at Goddard beginning about 8/17 and extending through about 8/23 on the Goddard record and 8/21 on the Rhode Island record. During this period the data at both stations appeared to be in reasonably good agreement in the green and the red; however, the blues at Rhode Island appeared to be a little on the high side. This resulted in somewhat higher alphas involving the blue channel. Nonetheless, the tendency for the alphas to decrease at the higher end of the spectrum was evident at both stations. Low green/red alphas occurred on a number of days during this period. It was also during this time that low alphas in the blue/green channel were noted during a several day period in Philadelphia. Consequently, we conclude that during this period the air mass conditions over the northeast in the general area of the experiment were relatively homogeneous and relatively clean.

Penn State

Two sun photometers were used at Penn State. Initially, UM 314 was in place. However, towards the end of September and into the beginning of October, there was evidence of sporadic malfunctioning of the blue channel. When this problem became evident, a second sun photometer, UM 311, was sent to Penn State. Intercomparisons between the two instruments were made at Penn State on October 11, 12, 18 and 19. For the most part the comparison between these two sets of readings was quite good. Unfortunately, the weather was poor during this period and an extensive series of readings was not possible. There was also evidence of some difficulties with cloud. During this intercomparison the blue channel was essentially inoperative. However, the difficultes with the blue channel apparently did not affect the other two channels.

There is evidence that the blue channel in UM 314 began to sporadically malfunction toward the beginning of the experiment in July. This is evidenced by sporadic negative values in turbidity and also unusually low, often negative, values for the alphas involving the blue channel. However, the turbidities measured in the green and the red channels seem to be reasonably consistent even when the values in the blue channel were wildly erratic.

On 10/17, turbidities were very low. There is some evidence of a gradual change in the alpha G-R which may be attributable to small but significant calibration errors which become evident because of the very low turbidities. On the whole, the alphas in the green/red are quite stable during the course of the day during most of the data days. This again suggests that the green and the red readings are reasonably accurate and stable.

St. Louis,

The St. Louis data was taken with sun photometer No. UM 303. This is a very nice data set. There are a lot of data points with many observations taken on most days when weather permitted.

A perusal of the data shows that the data looks internally consistent. Alphas are relatively constant across the spectrum except on a few days. This is true even on some days when the turbidities were relatively low - for example, on days 7/20, 7/21, 7/30 and 7/31. However, there were no days when the turbidity was consistently very low during the course of the day. Conversely, on some days turbidities were extremely high. On some of these occassions, blue/green alphas were relatively low compared to the blue/red and the green/red. An example is day 7/3.

The blue channel in this instrument seemed to perform

very well. On some days relatively constant blue turbidities were obtained throughout extensive sets of readings during the course of the morning. An example is on day 7/14. Day 8/5 is a bit unsual in that there were low alphas across the entire spectrum. The next day the same situation obtained. However, there was only two readings on 8/5 and one on 8/6.

Columbus, Ohio

This data set is a very nice and extensive one. The data recovery was very good. There is data for many days and on a large percentage of days the observer managed to take the total prescribed set of readings, seven. There were a number of days when the turbidities were relatively low and constant. Examples are on 9/9 and on 9/23. On these days the alphas were relatively uniform during the course of the measurements and they were essentially equal across the spectrum. Typical values were in the range of 1.1 to 1.8 or so. On a number of occasions the alphas in the blue/green were unusually low with respect to those in the blue/red and the green/red. Examples are on 7/6, 7/7, 7/8, 7/15, 7/23, 8/4, 8/5, and 8/27. The turbidity on many of these days was relatively high. Considering the fact that the alpha values were essentially constant on many of the other days, these days with low alphas in the blue/green are probably significant - i.e., these are not instrumental artifacts.

The validity of the data which show low alphas in the blue/green is further supported by comparing the Columbus data with the St. Louis data. The first day on which data was taken at both sites was on 7/7. On this day a similar alpha trend was noted at both sites. On the following day, 7/8, the turbidities were extremely high at Columbus but they were relatively low at St. Louis. In general, there was not a great deal of agreement between these two data sets. The turbidities, when they differed appreciably, were often extremely high; this difference appears to reflect the impact of local and regional pollutant sources. On 7/29 a relatively clean air mass appeared to have moved into the area and realtively low turbidities were noted at both sites. This continued through 7/31 at St. Louis and into 8/1 at Columbus. During this period St. Louis seemed to have relatively higher alpha values than did Columbus. Another period of relatively clean air began on 8/17 at Columbus and 8/18 at St. Louis. This persisted until about 8/20 or 8/21.

Some caution must be exercised in using the Columbus data and, to a certain extent, the St. Louis data. Because of the diligence of the observers, they often took observations under marginal cloud conditions. Anomalous data should be checked against the satellite photographs for evidence of cloud contamination.

Conclusion

The sun photometer data obtained in this experiment are probably the most extensive and coherent data set ever obtained in experiment of this sort. Although there were some instrumental difficulties and although weather did present a problem in the form of extensive periods of cloud, in general the quality and quantity of data was quite satisfactory.

Table 1

Sun Photometer Calibration Constants For Three Calibration Periods

Inst	Calib*	Blue	Green	Red	Water+	Notes
UM302	1	39.9	217.6	169.2	1.82	
	2	39.5	216.4	170.4	-	
	3	42.2	217.1	169.2	1.84	
UM303	1	70.6	227.6	173.5	1.76	
	2	67.4	222.6	172.3	-	
	3	68.7	225.6	169.3	1.79	
UM310	1	-	-	-	-	Instrument Malfunction During Test
	2	50.9	217.6	193.4	-	
	3	52.5	217.1	189.5	1.83	
UM311	1	62.3	234.3	146.4	2.38	
	2	65.6	237.5	147.9	-	
	3	68.2	242.7	152.1	2.37	
UM314	1	-	-	-	-	Not Run
	2	27.8	177.1	159.3	-	
	3	27.1	182.5	160.1	-	
UM315	1	43,8	206.3	182.2	1.74	
	2	46.2	209.4	186.7	-	
	3	49.1	209.9	188.9	1.63	
UM317	1	47.2	205.0	175.9	1.73	
	2	44.7	202.6	174.5	-	
	3	47.5	200.6	172.0	1.65	
UM319	1	-	-	-	-	Not Run
	2	46.0	181.6	149.5	2.15	
	3	47.7	180.0	149.5	2.10	
UM320	1	30.0	-	141.1	-	
	2	29.0	186.3	140.1	-	
	3	29.6	185.1	142.3	2.08	
UM322	1	32.1	185.5	150.9	1.90	Prime Langley Calibration
	2	Reference Instrument for this Calibration				
	3	36.3	190.8	151.0	1.83	
UM323	1	39.2	182.5	125.7	2.06	
	2	-	-	-	-	Not Run
	3	39.1	184.3	125.8	2.03	Prime Langley Calib (Boulder)

*Calibration Period

+Q_o

Table 2

Recommended Sun Photometer Calibration Constants *

Inst.	Blue	Green	Red	Water
UM302	40.9	216.8	169.8	1.84
UM303	68.1	224.1	170.8	1.79
UM310	51.7	217.4	191.5	1.83
UM311	66.9	240.1	150.0	2.37
UM314	27.5	179.8	159.7	-
UM315	47.7	209.7	187.8	1.63
UM317	46.1	201.6	173.3	1.65
UM319	46.9	180.8	149.5	2.13
UM320	29.3	185.7	141.2	2.08
UM322	36.3	190.8	151.0	1.83
UM323	39.1	184.3	125.8	2.03

*Simple mean of constants from calibration periods 2 and 3 except for UM322 and UM323 which are simply the values from calibration period 3. Water channel constants for all instruments are from the third calibration period only.

Table 3

Error Sensitivity in Alpha: Effect on Alpha of an Error of 0.01 in τ_R with τ_G Constant

	Nominal Value of (G - R)			
τ_R	0.1	0.5	1.0	1.5
	Error Range in Alpha			
0.025	-.500/1.00	-.100/1.40	.400/1.90	.900/2.40
0.05	-.233/.495	-.177/.895	.677/1.40	1.18/1.90
0.10	-.069/.286	.331/.686	.831/1.19	1.33/1.69
0.50	.065/1.04	.465/.504	.965/1.04	1.47/1.50

Table 4

Number of Observations Per Day at Each Station

July

Day	St. Lo.	Colo.	P.S.	Phila.	R.I.	God
1						
2	2				1	
3	5					
4						
5						
6	5	1	2		7	
7	7	6	6			23
8	6	7	5		6	
9	6	4	4		4	29
10	1	1	4		5	14
11	7	6	4		1	26
12		4	1		3	12
13	3					
14	7	6	3			1
15	3	6	5		6	14
16	2				5	
17	7	7	6	6	5	
18	2	5	5	2		14
19			1	3		6
20	7					
21	7			4		17
22	7	1		2		2
23		7	3	5		16
24	5	6			3	
25	3	7				
26	2					
27	1		1	3		
28		1				
29	5	2		3		
30	6	7	4		3	22
31	7	7	7	2	5	

Table 4 (Cont'd)

August

1	2	7	2			7
2	1	5				7
3	1				3	
4	7	3				
5	2	5			1	19
6	1				1	
7	4				1	
8	6					
9	7					8
10		4	1	3		
11	3		1			
12	7	5				
13	5	2				
14	2	2		3	1	15
15	1					
16				4		
17	3	7	4	2	5	20
18	7	8	7	4	5	16
19		7	2			
20	3	7	7	2	3	9
21	5	1	5	3	7	
22		1				
23		3	4			19
24		2		3	1	
25		4	2	3		14
26		5				
27		3	2			
28						16
29						
30						
31					2	

Table 4 (Cont'd)

September

1		4			1	
2			5			
3						
4						
5						
6						
7						
8		2	2			
9		7	1			18
10		4	2		2	
11		7	1/1		2	
12		6	2/2			
13						
14						4
15						End
16	2	1				
17	1					
18	2		2/2			
19		4	2/2			
20	1					
21	2			4		
22						
23	2	5		6		
24		4	/1	5		
25						
26						
27	1					
28	2	5	1	2		
29	3	1	1	4		
30	2					
31						

Table 4 (Cont'd)

October

1	1				
2	2				
3					
4			1	1	
5		2			
6	1				
7	1	2			
8	2	4			
9	1		3	1	
10	End				
11					
12		6	1		
13		3	3	1	2
14		2	5	3	End
15		End	1		
16				2	
17			5	2	
18					
19				2	
20			2	2	
21			End	2	
22				End	

Appendix I

Sun Photometer Measurements

Instructions to Observers

SUN PHOTOMETER MEASUREMENTS

NORTHEAST TURBIDITY (NET/81)

Dr. J.M. Prospero and Mr. T. Snowdon
University of Miami,
Rosenstiel School of Marine and Atmospheric Science
4600 Rickenbacker Causeway
Miami, Florida 33149

Telephone: Prospero-305/350-7440
Snowdon-305/350-7464

PURPOSE

The measurement of the intensity of direct solar radiation in narrow wavelength bands enables us to determine the amount of aerosol extinction (turbidity) and the spectral dependency thereof. The measurements which you make will provide ground truth for a satellite program which endeavors to develop techniques for the remote sensing of pollutant aerosol concentrations.

INSTRUMENT

The sun photometer is similar to a photographic exposure meter with a very narrow viewing angle. Your instrument measures at four wavelengths: 1) 380 nm, which we will refer to as the blue (B) wavelength; 2) 500 nm, which we will refer to as the green (G) wavelength; 3) 875 nm, which we will call the red (R) wavelength; 4) 945 nm, a water vapor wavelength (W). The instrument is also used to measure the relative optical path length, or air mass, (M).

The instrument functions as follows: Filters are mounted on a disc that is rotated by the large knob at the rear of the box. The filter can be viewed through the glass cover plate at the front of the box by removing the snout cover. The readout device is a liquid crystal display (LCD). With the Function knob on the top of the case placed in the PreAmp (PA) position, the amplified voltage output of the silicon detector is read by the LCD voltmeter. With the knob placed in the Peak Hold (PH) position, an electronic circuit is incorporated which records and holds the maximum reading obtained. The third position, Thermistor (T) yields an analog (not true) temperature reading of the silicon detector; the reading increases with decreasing temperature. In routine operation, only the Peak Hold and Thermistor functions will be used.

The diopter arm along the side of the case is used to measure the solar elevation in terms of the relative path length through the atmosphere (M). At solar noon, M=1 and it increases with increasing angle from the zenith.

MAKING MEASUREMENTS WITH THE SUN PHOTOMETER

A) Turn on the instrument as soon as you pick up the instrument to walk to the observing site. Carry the instrument with the strap around your neck or use the carrying case if one is supplied; do not use the neck strap as a hand carrier - there is danger that the swinging instrument might strike something.

B) Pick a site that is relatively protected from the wind if possible.

C) Time. Immediately prior to making a solar reading, note the Local Daylight Saving Time to the nearest minute. Use the watch on the photometer; it is set to your local daylight saving time.

D) Temperature Reading. Place the Function switch in the Thermistor position and record the LCD reading on the data sheet. (This is not a true temperature).

E) Solar Reading. Function switch in Peak Hold position:

1) With the Filter knob in the Blue position, momentarily press the Reset button and then aim the instrument at the sun so that the sun spot falls on the target. It is not necessary to have the spot precisely on the target; instead, sweep the spot repeatedly across the target until the LCD reading is stable. (In practice, the last digit may wander up or down a few units - this is acceptable). This sweeping action should take only several seconds. Note the reading; Reset and repeat the procedure to verify the reading. Always Reset the instrument when it is pointed at a relatively dark part of the sky or at the ground. It will not Reset properly to zero when pointed at the sun.
   a) Switch to Green and repeat the sequence.
   b) Switch to Red and repeat the sequence.
   c) Switch to W and repeat.
2) Note the time.
3) Set the Function switch to Thermistor and note the reading.
4) Return the Function switch to Peak Hold and repeat the entire sequence.
   a) Time
   b) Thermistor
   c) Blue readings
   d) Green readings
   e) Red readings
   f) "W" reading
   g) Solar elevation reading M. The value of the relative optical path length (M) is read at the point where the top of the case intersects the diopter scale-see figure. (M is a measure of the optical path length through the atmosphere. When the sun is directly overhead, M=1. An M value of 3, for example, indicates a path length through the atmosphere that is 3 times that with the sun overhead).
   h) Time
   i) Thermistor reading

The second set of readings should be within several percent of the first set. If not, thin high cirrus may have been present or the readings may not have been made carefully. To check the latter possibility, repeat the reading sequence.

If you have notes or comments, write them out on the line immediately under the data line.

Time readings must be accurate to within one minute.

F) At the completion of the readings, turn the instrument to Peak Hold and OFF and return it to its storage place.

G) Record all data on the forms which we supply. Always make a carbon copy. Mail each week's supply of data to us on Friday evenings. Send the original. Keep the carbons until the end of the experiment when you can mail them as a batch.

We encourage you to have some patience during the first few days of using this instrument. After a little experience, the measurements will not take more than several minutes.

WHEN TO MAKE READINGS

Readings will be made only during the morning hours up to about solar noon. There is a tendency for cloud to build up later in the day; this makes satellite data interpretation difficult. Hence, we will not ask for afternoon readings.

Your schedule calls for a series of four prime readings spaced throughout the morning. You will be reimbursed for these readings. You also have the option of taking as many as three additional measurements for which you will also be reimbursed, but at a lesser rate. The rationale for selecting these times will be more obvious if you refer to the appended figure which shows the value of M (the relative atmospheric optical depth) as a function of time on selected dates at your location. The first measurement is scheduled for 7:00 a.m. or earlier (see appended diagram). This time yields a relatively high value for M; also, convection should be minimal at this hour. The second, third and fourth prime measurement time slots are progressively longer because the rate of change of M is progressively slower. In recording the time of measurements in the early hours, it is necessary to be accurate to within $\pm$ 1 minute because of the rapid change in M. Although we will use your measured value of M in the computer computations, we will also calculate the value of M for verification purposes.

The Additional Measurements A, B and C are interspersed between the Prime Measurements. Note that you must allow a gap of about 15 minutes or more between the Prime Measurements #1, #2 and #3 and the Additional Measurements A and B. Measurement C must be separated by at least 30 minutes from #3 and #4. The objective is to get a set of measurements that are relatively uniformly distributed throughout the morning.

The gratuity scale is as follows:
#1 = $1.75
#2, 3, 4 = $1.25 each
#A = $0.75
#B, C = $0.50 each.

Also, the person making the greatest number of useful readings will receive a bonus of $100. Those in second and third place will receive $50 and $25, respectively. Thus, a person making prime measurements every day during July and August will receive a total of $341. If all possible additional measurements are also made, the total will be $450. There is also the added possibility that you might win a bonus. Remember, however, that only valid measurements will be reimbursed. Measurements made through cirrus or in areas of heavy cloud (both of which are discernable in our satellite imaging) are obviously invalid.

WHERE TO MAKE READINGS

You may make readings anywhere within the general area of the town or city specified in your address. For example, you can make the early morning readings

at your home and the later readings at your lab. However, if you make readings at locations other than the laboratory address, please give us the precise address of such locations the first time you take readings at that location. Thereafter enter a brief note in the Notes column as to the location (i.e., home, lab, etc.). Always carry the instrument in the carrying case provided. Do not let the case stand in the sun for long periods.

Do not make readings when there is cirrus over the sun or when clouds are over or within a few degrees of the sun.

COMMENTS ON TURBIDITY MEASUREMENT TECHNIQUES:

Always record the maximum reading; the maximum reading will not necessarily be obtained with the aiming spot directly on the target.

The Blue channel readings will always be much lower than those in the Red, Green, and "W" channels.

Occasionally check the glass plate covering the aperture at the front of the instrument, take off the snout aperture and look down the tube. If it is dirty, remove the snout and wipe very carefully with optical tissue.

If you take the instrument from an air conditioned room to a hot, humid environment, condensation may develop on the glass cover plate. It is best to store the instrument at a temperature that is not too different from that of the outside air.

Do not let the instrument sit in the sunlight for long periods of time - it can get quite hot and affect the calibration.

The instrument does not like being dropped. If it is dropped, make a note in the log sheet so that we will be alerted to possible changes in instrument characteristics.

You may find that the last digit on the LCD display has a tendency to wander. This is especially true for the blue channel which has a very high gain. A wander of a few tenths (i.e., in the last digit to the right) is not significant. However, if the wander approaches one digit in the units column, make a note in the data sheet and inform us by telephone.

Please call either Prospero or Snowdon if you encounter any problems. We will have several spare instruments on hand to replace any faulty units.

About once a week, make a check of the sun photometer watch against an accurate time source. Record the clock time (hours; minutes; seconds) the instant that the watch minute readout changes. It is not necessary to reset the watch time. The watch is set for Local Daylight Saving Time. The watch has a readout of month and day which is activated by pressing the button on the side once.

BATTERY CHECK AND REPLACEMENTS

UM SERIES - 300 Sun Photometers with 4 filters contain three (3) 9v batteries (see wiring diagram):

1. Battery #1 powers the peak hold and temperature circuits as well as providing positive voltage for the photo-detector/amplifier. This battery provides more current, 7-10 ma in the temperature mode, than the other two batteries. Test Jack #1 provides access to Battery 1 and must be read with the photometer ON and in either the PEAK HOLD or PREAMP mode (i.e., not in the Temperature mode).

2. Battery #2 provides negative voltage for the photo detector/amplifier (B&H529). Only 0.4 ma are drawn form this battery, so it should last indefinitely under normal use. Test Jack #2 accesses this battery.

3. Battery #3 provides power to the voltmeter board and the digital display. This battery only needs to deliver 1.2 ma; it too should last many months in routine service.

The battery test need only be made every few weeks unless there is a possibility that the instrument has been left ON for an extended period of time (more than a few hours).

Checking the Batteries: Test Pin Jacks are provided for batteries 1 and 2.

1. Place instrument ON and in PEAK HOLD or PREAMP position.

2. Connect the positive lead of a voltmeter to the appropriate pin jack and the negative lead to the large strap screw-head next to jacks.

3. Voltmeter should read in the range of 7.0 to 9.1v. If the battery yields less than 7.0v, it must be replaced.

4. There is no test jack for battery #3 (voltmeter board). A weak battery is indicated by a feeble display.

Battery Replacement:

1. Unscrew four rubber feet and remove bottom plate from instrument.

2. Remove styrofoam wedge and lift out batteries.

3. Batteries can be easily identified by checking the destination of the black lead from the battery clip.

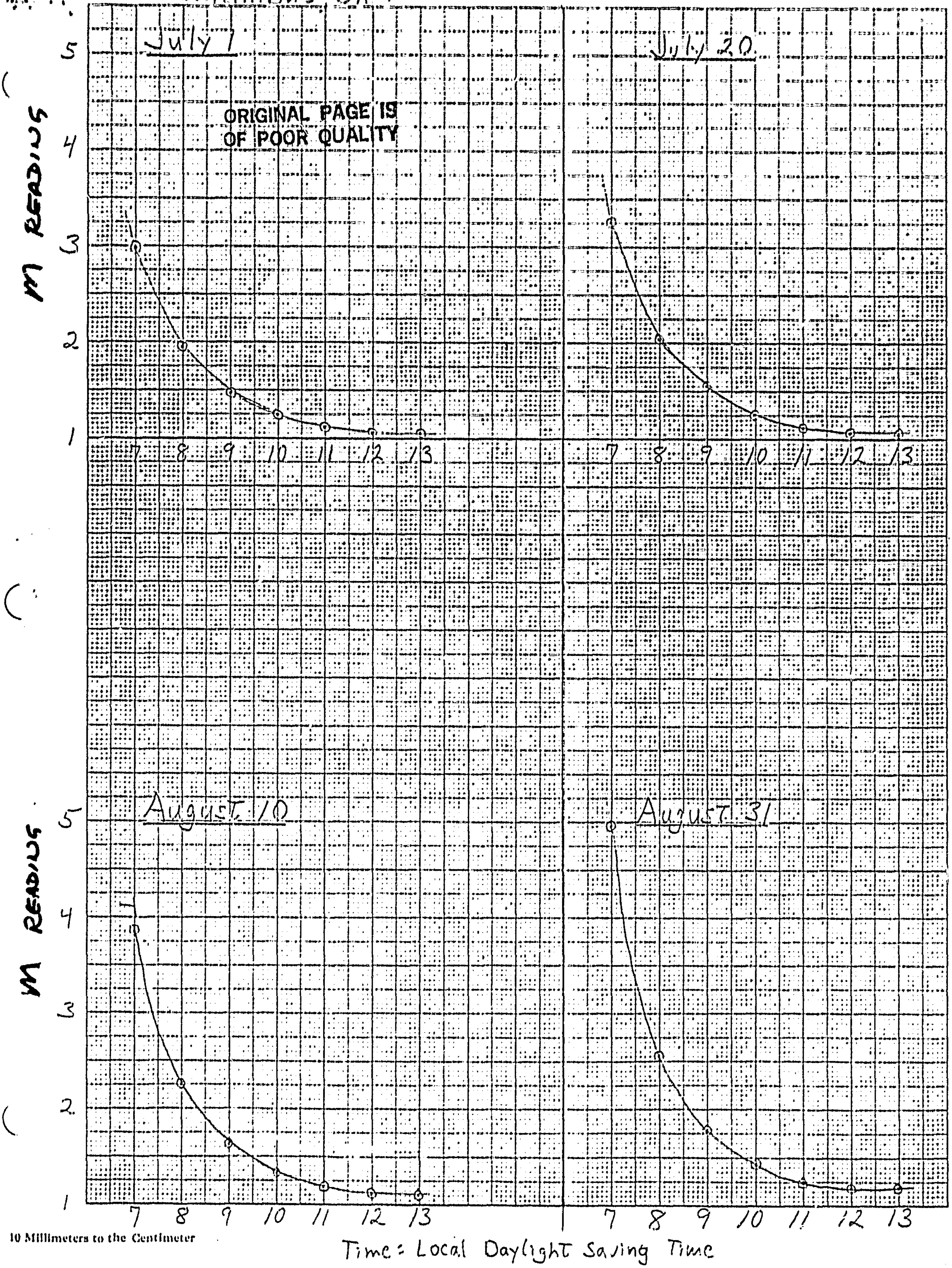
    a. Black lead to outer (light green) circuit board on right - Battery 1.
    b. Black lead to dark green integrated circuit socket on left - Battery 2.
    c. Black lead to inner (dark blue) voltmeter circuit board on right - Battery 3.

4. <u>If any one battery is weak, replace all batteries.</u>

5. Batteries should be replaced with fresh 9v alkaline transistor batteries (MN1604, V51323, or equivalent). We will reimburse you for the cost of replacement batteries if you send a receipt for their purchase.

6. Always turn off the instrument when replacing the batteries.

Columbus, Ohio



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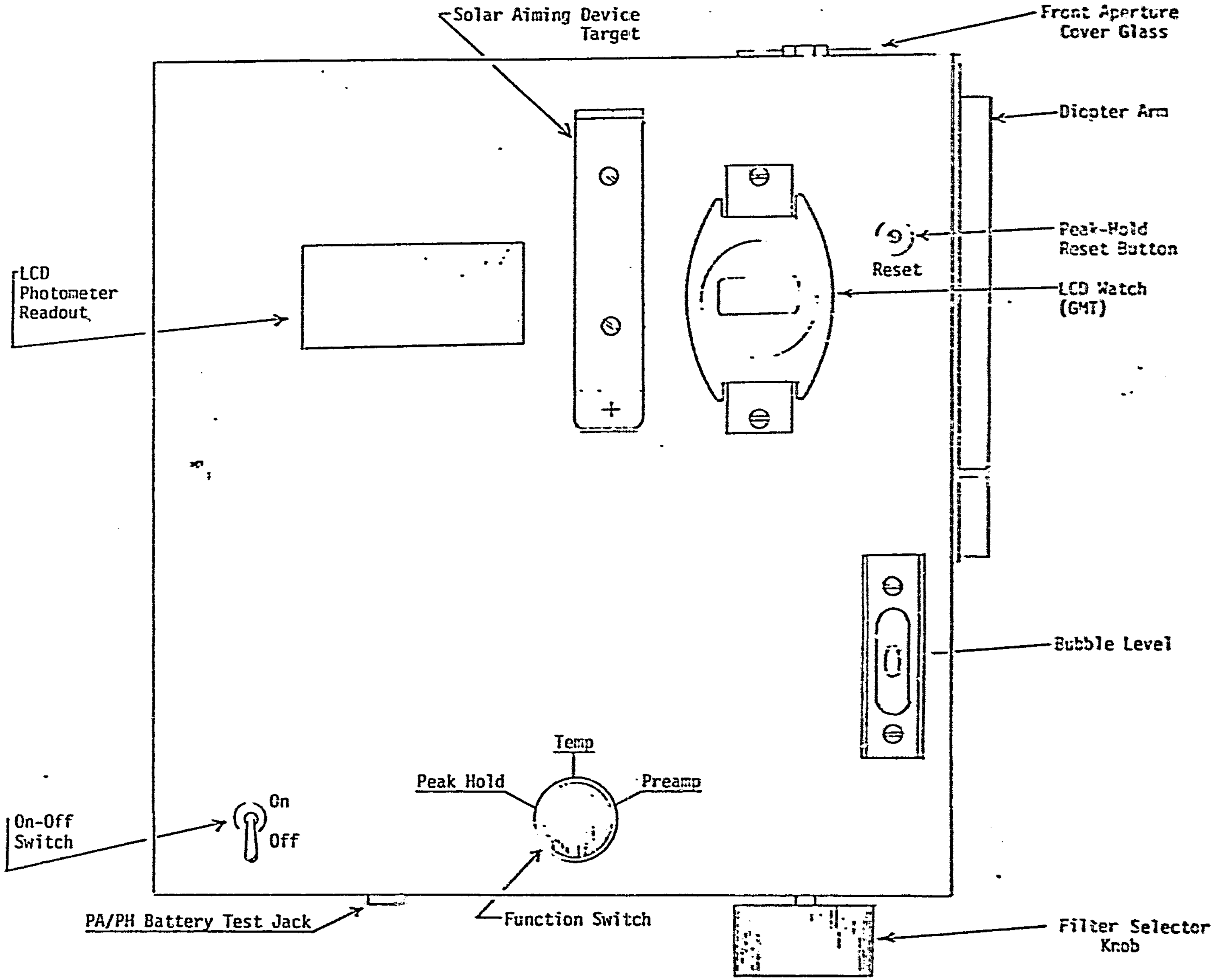
10 Millimeters to the Centimeter



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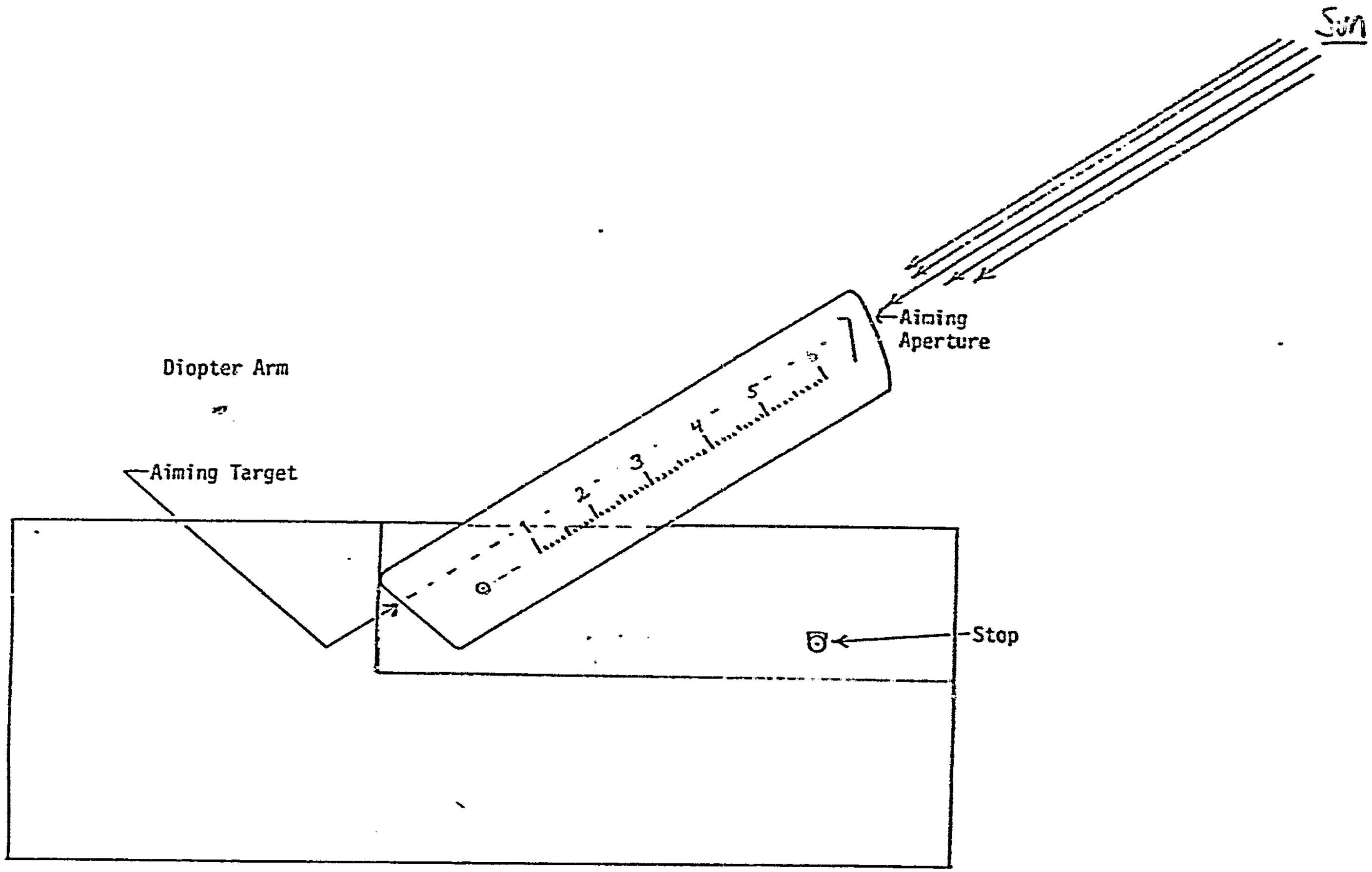

Hold the photometer level by means of Bubble Level; raise arm so that sun spot falls on the aiming target. Read intersection of top of side plate and the scale on the diopter arm. In this example, it reads 1.75.

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Appendix II

Observation Stations and Observers

Appendix II

Observation Stations and Observers

Philadelphia	Terry Bandy	- Drexel Univ. Bryn Mahr	75:10W 40:00N 75:26W 39:95N
	Ruth Alee	- Drexel Univ. Home	75:10W 40:00N Same
NASA/Godadard	Wang	- GSFC	77:00W 38:92N
	Fraser	- Kimberly Rd. or Fredrick (Md. ?) or Washington Pk.	
URI	R. Cayer	- Narragansett, RI	71:45W 41:43N
St. Louis	J. Hulka	- Washington Univ.	90:25W 38:67N
PSU	D. Kabel	- St. College, Pa. Clearfield, Pa.	78:54W 41:11N 79:23W 41:02N (7/11/81 only)
	M. Nichols	- St. College, Pa. Centre Hall, Pa.	78:54W 41:11N (began 9/11/81) 77:58W 40:92N
OSU	W. Stockwell	- Columbus, Ohio	83:05W 39:98N

Appendix III

Cover Letter to Observers

University of Miami
Miami, Florida 33149

DIVISION OF MARINE GEOLOGY AND GEOPHYSICS
Dorothy H. and Lewis Rosenstiel
School of Marine and Atmospheric Science
4600 Rickenbacker Causeway (305) 350-7508

June 22, 1981

Dear Colleague:

First, we wish to thank you for agreeing to cooperate in this experiment. The objective of our program is to use remote sensing techniques to measure the vertically integrated aerosol concentrations in pollution episodes. Dr. Robert Fraser (NASA/Goddard) will use various satellites, principally the geostationary satellite (GOES) and the Coastal Zone Color Scanner (which actually scans well inland), to measure surface brightness values which can be inverted to yield aerosol optical depth estimates. The sun photometers which we are placing in the field will provide ground truth measurements which Dr. Fraser will subsequently fold into his inversion model.

The sun photometer is fully described in the appended literature. Briefly, it is a device for measuring the direct solar radiation intensity in relatively narrow passbands (380 nm, 500 nm, 875 nm, and 940 nm). The presence of aerosols will result in a reduction of the direct solar radiation through the atmosphere because of scattering and/or absorption by particles in the optical path.

The measurement protocol is fully described in the instructions. Briefly,we are asking you to make measurements during specified time periods during the morning during July and August. You will be paid for each measurement that you make. There are four prime measurements. You will be paid $1.25 for each of these except the first for which you will receive $1.75 (because it is relatively early in the morning). Note that the allowable time slot broadens as the morning progresses. This is so because the rate of change of the light path through the atmosphere is greatest at low sun angles. You may take additional readings at times other than the prime time slots as shown in the schedule; you will be paid $0.75 for the first reading and $0.50 for the others up to a maximum of $1.75 per day. There will be a bonus of $100.00 for the person who takes the greatest quantity of valid data during July and August, a bonus of $50.00 for the person who takes the second greatest quantity of data, and $25.00 for the third greatest. Payment will only be made for valid data including both Prime Measurements and Additional Measurements. There will be a total of five paid observer stations in the network.

We will be analyzing all satellite data for the months of July and August including weekends. Thus sun photometer data for weekends will be utilized. We encourage you to make weekend measurements.

The instrument is so easy to use that you may want to teach more than one person to use it and to make readings. However, you must be careful that, in assigning more than one person to make readings, the readings don't get taken because person A thought B was doing it while B thought otherwise.

We will be most happy to supply all interested parties with aerosol optical depth values once we have completed the computations. Note that one channel (940 nm) will give us a measure of precipitable water, a number which may be of interest to some of you.

We will ship all instruments this week. We hope that you will immediately begin to use your instrument so that you will get a feel for the instrument and verify that it has not been damaged in shipment. If you have any difficulties or questions, please call us collect. We have several spare photometers with which we can replace malfunctioning units. One of us (J.M.P.) will be away from 27 June until 28 July, but the other (T.S.) will be here at all times. The telephone numbers are: Joe Prospero, 305/350-7440; Tom Snowdon, 305/350-7464.

Please return data sheets by mail each Friday night at the end of operations. This enables us to check the data for internal consistency. A supply of self-addressed stamped envelopes are enclosed with the photometer.

Please advise us as soon as possible of telephone numbers where you can be reached while in the field.

Thank you and good luck.

Sincerely,

Joseph M Prospero

Joseph M. Prospero
Professor
Marine Geology and Geophysics

Thomas Snowdon
Research Assistant

JMP/mh

Appendix IV

Standard Data Form

ATMOSPHERIC TURBIDITY DATA FORM: NET/81 . J. M. Prospero/T. Snowdon; U. Miami, RSMAS; Miami, Fla. 33149. 305-350-7440/7464

STATION:________ LOCATION:________ OBSERVER:________ PHOTOMETER #:________

	Month	Day	Time	Therm.	Blue	Green	Red	W	M	Time	Therm.	OFF!?
1												OFF!?
2												OFF!?
3												OFF!?
4												OFF!?
5												OFF!?
6												OFF!?
7												OFF!?
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29												OFF!?

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30 Weekly time check of photometer watch against an accurate time standard (hours, minutes, seconds)

31 Month ____ Day ____ Watch Time ____ Standard Time ____

→ RETURN DATA SHEETS BY FIRST CLASS MAIL EVERY FRIDAY NIGHT. THANK YOU. ←

Appendix V

Letter Confirming Receipt of Data:

R. Fraser

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland
20771

NASA

Reply to Attn of: 915

FILE 14139

Professor Joseph M. Prospero
Division of Marine and Atmospheric Chemistry
4600 Rickenbacker Causeway
University of Miami
Miami, FL 33149

JUL 14 1983

Dear Joe:

I have received from you the solar transmission data taken during the summer and fall of 1981 under Contract NAS5-26768. These data are given on IBM cards and are listed on tabulations. I shall return your 3 transmissometers to you at the end of this month.

Sincerely,

Bob

Robert S. Fraser
Climate and Radiation Branch
Laboratory for Atmospheric Sciences

REPORT OF INVENTIONS AND SUBCONTRACTS

(Pursuant to "Patent Rights" Contract Clause) (See Instructions on Reverse Side)

FORM APPROVED OMB NO. 22-R160

1. NAME AND ADDRESS OF CONTRACTOR *(Include Zip Code)*	2. CONTRACT NUMBER
Joseph M. Prospero, Dennis Savoie, Thomas Snowdon and Paul Ewbank University of Miami, Rosenstiel School of Marine and Atmospheric Science 4600 Rickenbacker Causeway, Miami, FL 33149	NAS5-26768
	3. TYPE OF REPORT *(Check One)* ☐ a. INTERIM ☒ b. FINAL

SECTION I - INVENTIONS *("Subject Inventions")*

4. INVENTION DATA *(Listed below are all inventions required to be reported) (If "None," so state)*

(i) NAME OF INVENTOR(S)	(ii) TITLE OF INVENTION	(iii) CONTRACTOR DISCLOSURE IDENTIFICATION NUMBER OR PATENT APPLICATION SERIAL NUMBER	(iv) CONTRACTOR ELECTS TO FILE U. S. PATENT APPLICATION		(v) CONFIRMATORY LICENSE OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER	
			YES	NO	YES	NO
	NONE					

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SECTION II - SUBCONTRACTS *(Containing a "Patent Rights" Clause)*

5. SUBCONTRACT DATA *(Listed is information required but not previously reported for Subcontracts) (If "None," so state)*

(i) NAME AND ADDRESS OF SUBCONTRACTOR *(Include Zip Code)*	(ii) SUBCONTRACT NUMBER	(iii) SUBCONTRACT PATENT RIGHTS CLAUSE	(iv) WORK TO BE PERFORMED UNDER SUBCONTRACT	(v) SUBCONTRACT DATES	
				AWARD	COMPLETION
			NONE		

SECTION III - CERTIFICATION

CONTRACTOR CERTIFIES THAT PROMPT IDENTIFICATION AND TIMELY DISCLOSURE OF SUBJECT INVENTIONS PROCEDURES HAVE BEEN FOLLOWED

DATE	NAME AND TITLE OF AUTHORIZED OFFICIAL *(Print or Type)*	SIGNATURE
7/21/83	Joseph M. Prospero, Professor	Joseph M Prospero